TOF measurements with MCP's

J. Va'vra, SLAC

Light travels 300μm in one ps

Point this talk

- **Two possible directions to make a TOF counter:**

- High gain MCP operation

- detector is **sensitive to single photoelectrons**.
- excellent TOF resolution of 5-10 ps; thin radiator of 3-5 mm possible.
- possibly serious QE aging problems.

SuperBelle: MCP rate of single pe's could be easily **> 100 kHz/cm²** at L ~ 10^{36}/cm²/sec

(TOP counter in the barrel region)

- Low gain MCP operation

- detector is **sensitive to tracks only**, and not sensitive to single photoelectrons.
- Somewhat worse TOF resolution of 15 ps; thicker radiator of 7-10 mm.
- possibly much smaller QE aging problems.

SuperB: MCP track rate is expected to be only **< 2 kHz/cm²** at L ~ 10^{36}/cm²/sec

(Forward TOF counter in the endcap region)

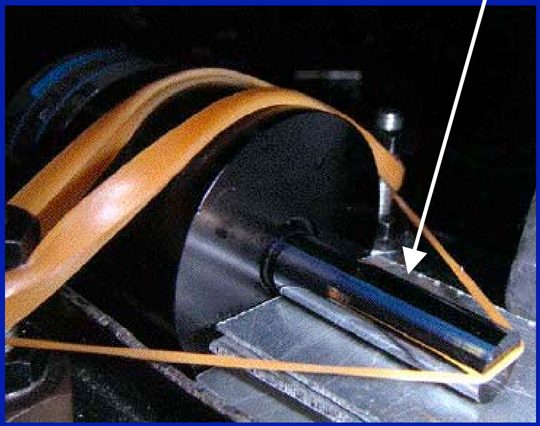
High gain operation

Example: Nagoya TOF counter

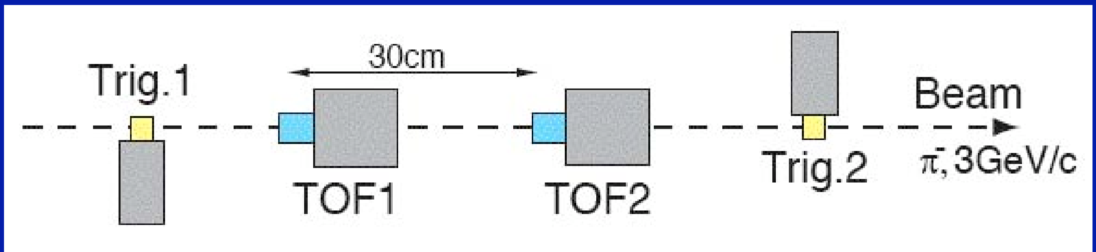
The Nagoya test in the beam

K. Inami, H. Kishimoto, Y. Enari, M. Nagamine, and T. Ohshima, " A 5 ps TOF-counter with MCP-PMT", Nucl. Instr. & Meth., A560(2006)303-308.

Vary the length



Beam test setup: two identical TOF detectors



- **Quartz radiator:** **10 mm dia. rod, coated with Al on its round sides, and Length: 40, 30, 20, 10 mm and no radiator (just a 3 mm quartz window).**
- **They claim: Npe ~ 20 for L = 3 mm, and Npe ~ 40-50 for L = 10 + 3 mm.**
- **The best resolution result was obtained for L = 10 + 3 mm.**

Hamamatsu MCP-PMT TTS measurement

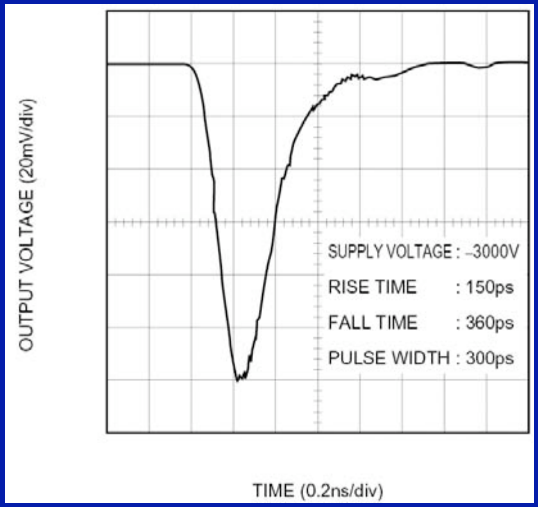
Hamamatsu data sheets

MCP-PMT R3809U-50:

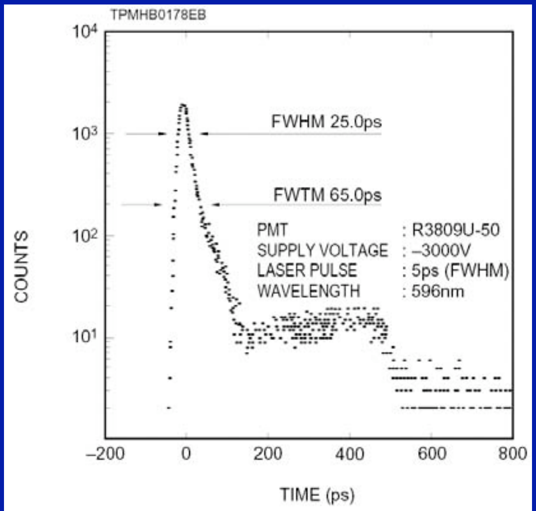
- **6 μm MCP hole diameter**
- Useful photocathode dia.: **11 mm,** Single pixel device
- Rise time: **~150 ps**.
- **Multi-alkali photocathode** (NaKSbCs), **QE ~ 26%** at 407nm.
- MCP-to-anode capacitance: **~3pF**
- **σ_{TTS} = 10-11 ps**
- HPK C5594-44 amp., **1.5 GHz BW, 63x gain**
- Laser light source jitter contribution: **σ ~ 2.1 ps**

  (Red wavelength of Nd-YAG laser: **λ = 596 nm**)

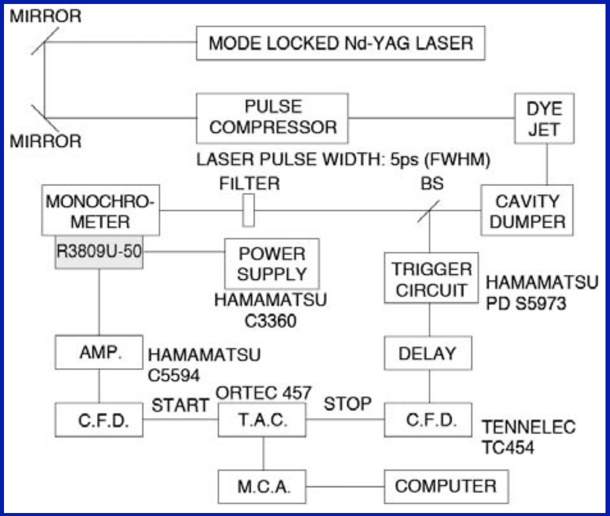
Rise time: ~150ps



TTS distribution:



Nd-YAG laser setup to measure σ_{TTS}:

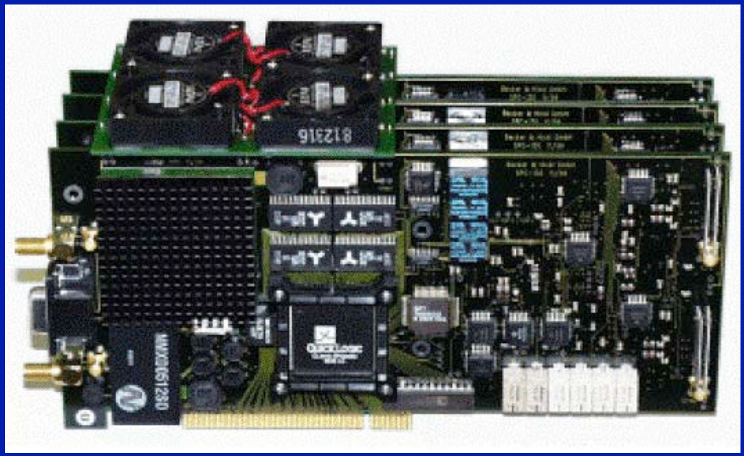


Electronics resolution

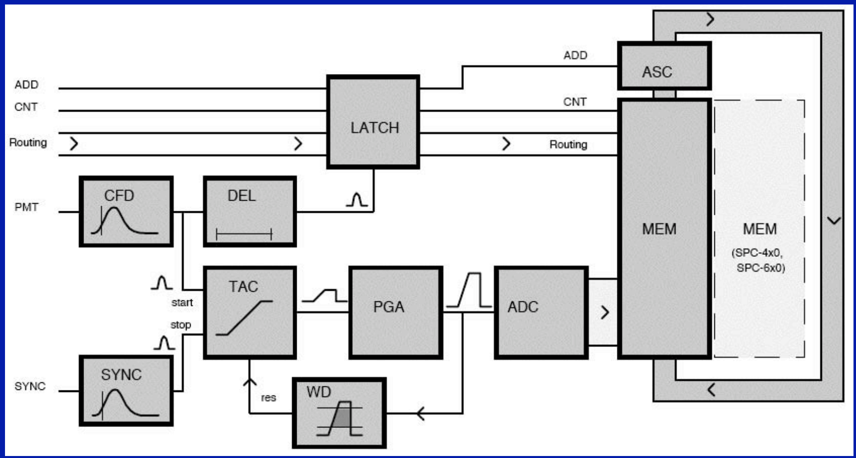
K. Inami, H. Kishimoto, Y. Enari, M. Nagamine, and T. Ohshima, " A 5 ps TOF-counter with MCP-PMT", Nucl. Instr. & Meth., A560(2006)303-308.

Time-correlated single photon counting module :

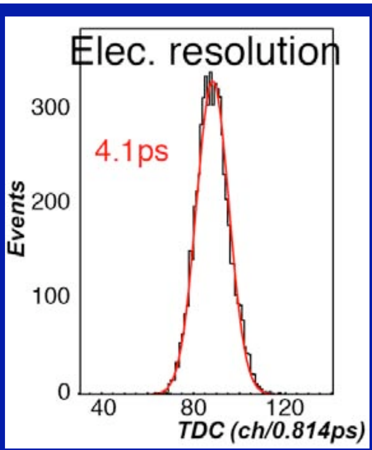
Becker & Hickl GmbH **SPC-134**



CFD/TAC/ADC



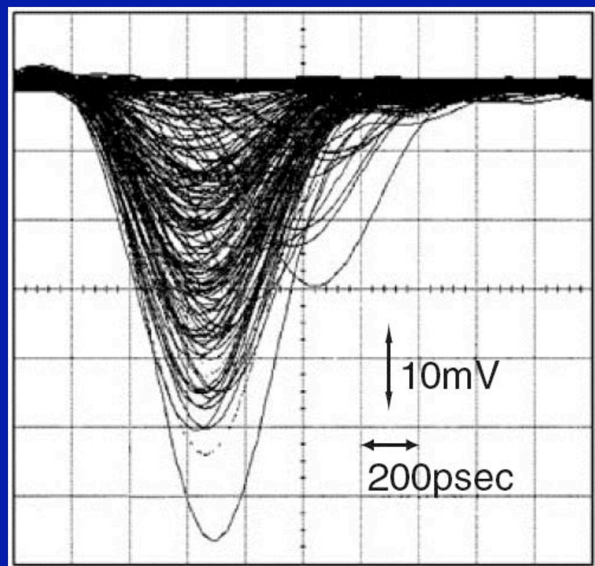
- **813 fs / count**
- **Time resolution achieved: $\sigma_{Electronics} \sim 4.1$ ps**
- **This result is slightly better than our Fermilab test beam result, however, worse than my bench tests at SLAC. In other words, the Ortec CFD/TAC/ADC electronics pretty good.**



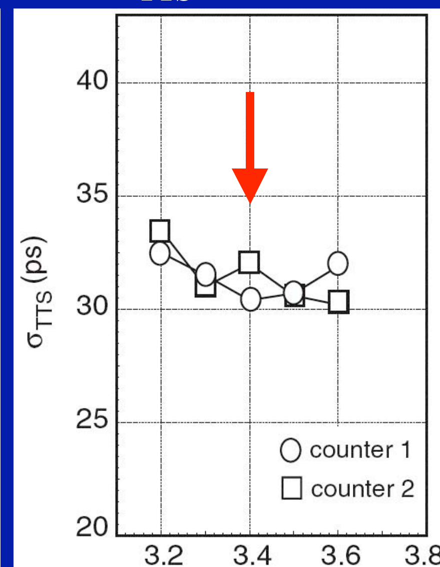
Single photoelectron response with a laser

K. Inami, H. Kishimoto, Y. Enari, M. Nagamine, and T. Ohshima, " A 5 ps TOF-counter with MCP-PMT",
Nucl. Instr. & Meth., A560(2006)303-308.

MCP-PMT R3809U-50:

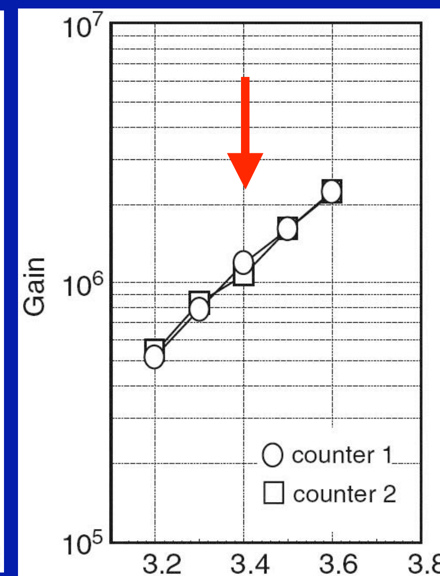


σ_{TTS} = f(HV)



HV [kV]

Gain = f(HV)

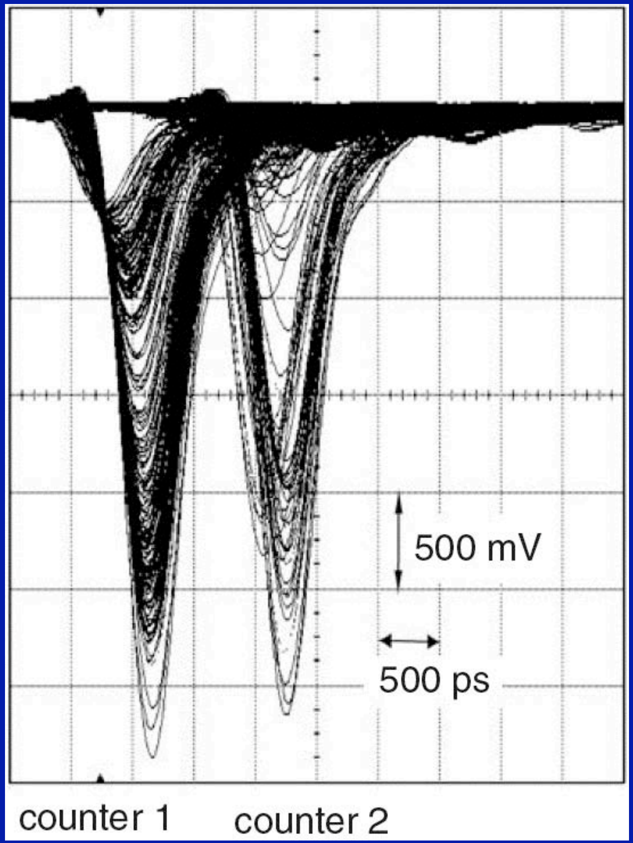


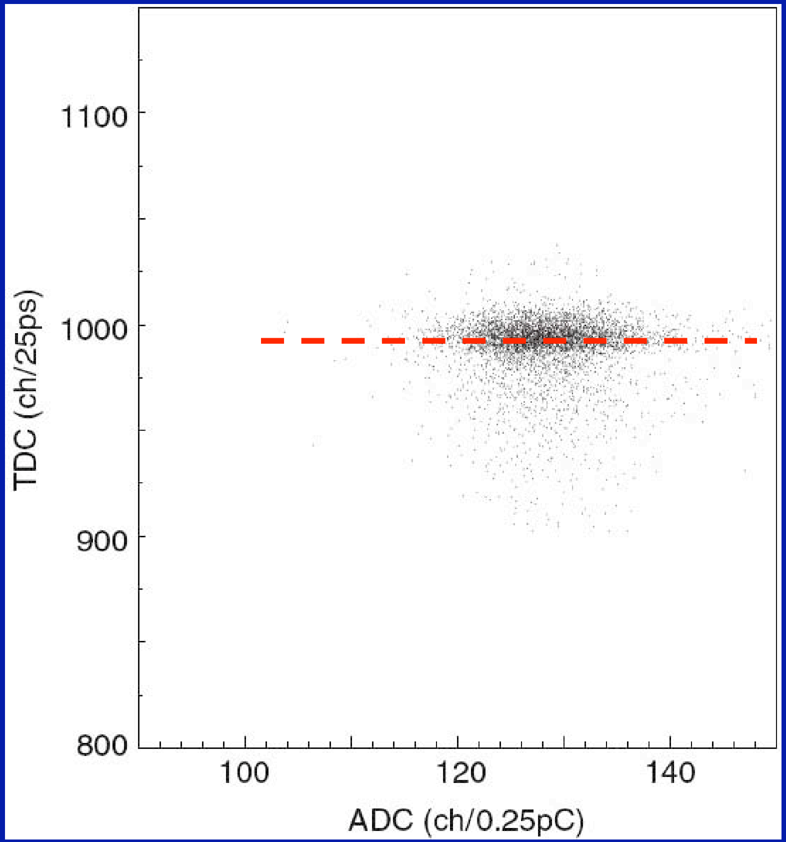
HV [kV]

- **They operated the device at a very high gain of ~2x10^6 at 3.4 kV.**
- **They measure σ_{TTS} ~ 32ps, even though Hamamatsu says σ_{TTS} ~ 10-11 ps.**
- No reply when I asked why they did not use the Hamamatsu number.
- **Inami told me that they have operated the beam test without an amplifier.**
- No reply to my question if pulses saturated for longer radiators.

Detector response in the beam

K. Inami, H. Kishimoto, Y. Enari, M. Nagamine, and T. Ohshima, " A 5 ps TOF-counter with MCP-PMT",
Nucl. Instr. & Meth., A560(2006)303-308.





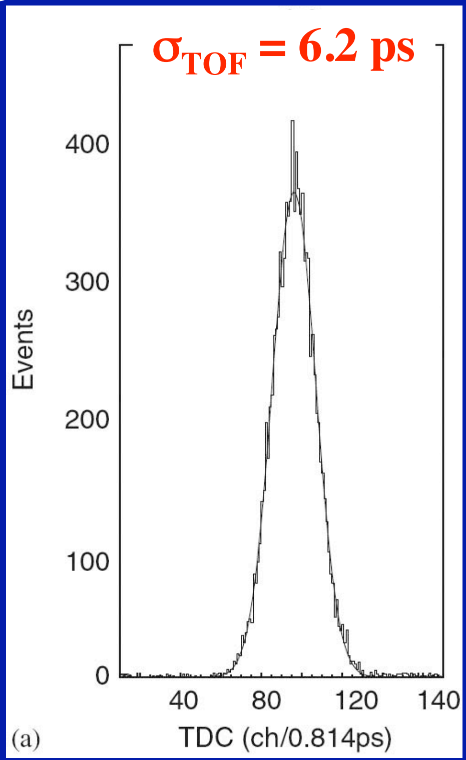
- **No dependence of timing on ADC - in contrast to our test at Fermilab**
- **No amplifier used in the Nagoya test.**

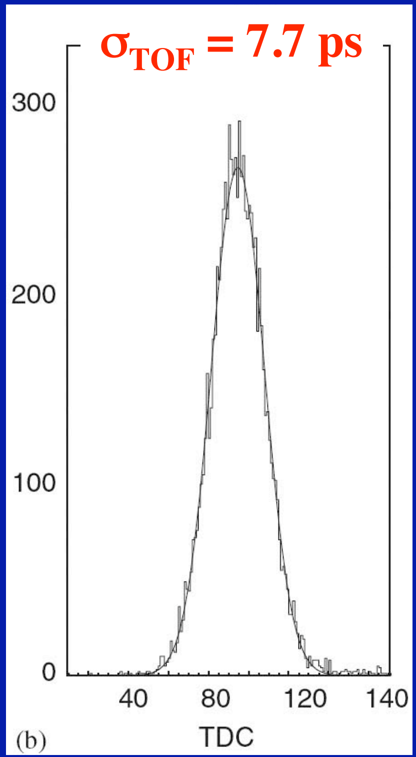
The best beam results so far

K. Inami, H. Kishimoto, Y. Enari, M. Nagamine, and T. Ohshima, " A 5 ps TOF-counter with MCP-PMT",
Nucl. Instr. & Meth., A560(2006)303-308.

Quartz radiator length: **10 + 3 mm** **3 mm**

Single detector resolution:





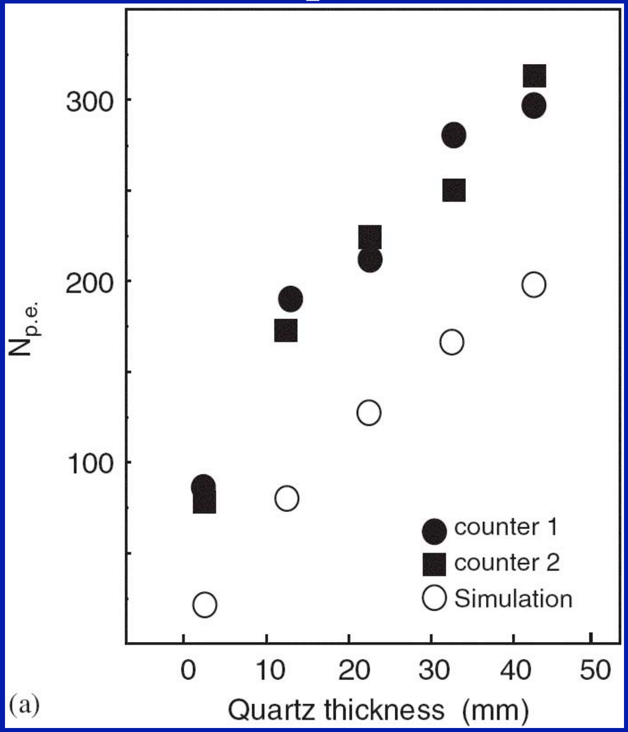
$$\sigma_{TOF} = \sigma_{measure}/\sqrt{2}$$

- **Two identical HPK MCP-PMT R3809U-59-11 with 6 μm holes.**
- **MCP-PMT operated at a very high gain of ~2x10^6.**
- **No amplifier to avoid saturation effects in CFD timing**

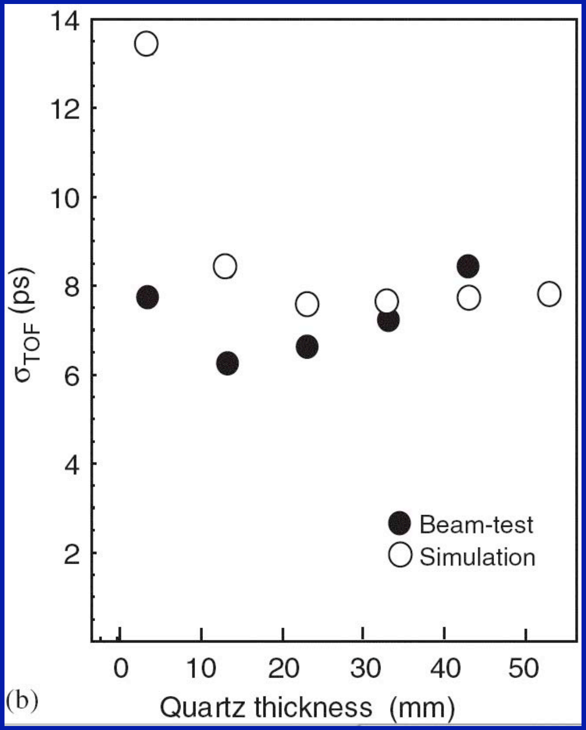
How well do we understand it with MC ?

K. Inami, H. Kishimoto, Y. Enari, M. Nagamine, and T. Ohshima, " A 5 ps TOF-counter with MCP-PMT",
Nucl. Instr. & Meth., A560(2006)303-308.

Npe



Data & MC



- **Mystery #1: Measured number of Npe is <u>SIGNIFICANTLY</u> larger than expected.**
- **Mystery #2: MC does not reproduce data well.**
- **Mystery #3: L = 10 mm gives the best resolution; MC predicts L = 20-30 mm.**

A simple calculation ?

My version of simple model (Nagoya people have similar but less correct formula in the paper)

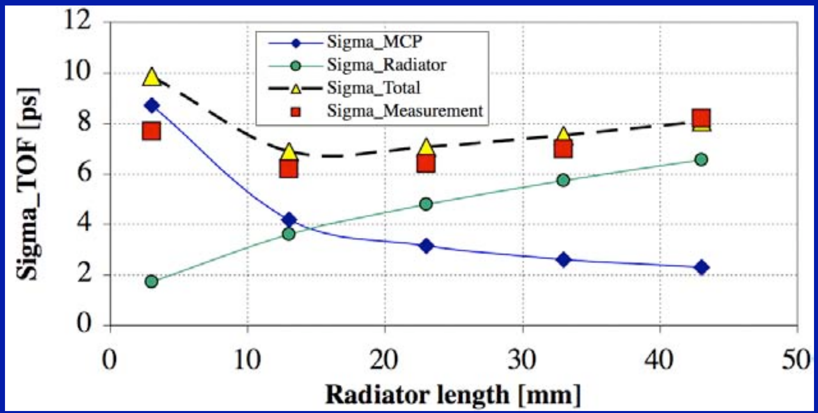
$$\sigma_{TOF} \sim \sqrt{[\sigma^2_{MCP\text{-}PMT} + \sigma^2_{Radiator} + \sigma^2_{Pad\ broadenibng} + \sigma^2_{Electronics}]} =$$

$$= \sqrt{[(\sigma_{TTS}/\sqrt{N_{pe}})^2 + (((L*1000\mu m/\cos\Theta_C)/(300\mu m/ps)/n_{group})/\sqrt{(12Npe)})^2 +}$$

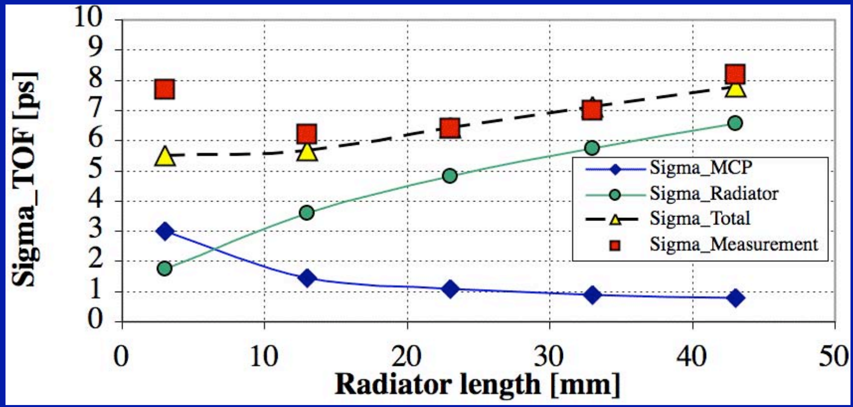
$$+ ((5*1000\mu m/300\mu m/ps)/\sqrt{(12Npe)})^2 + (4.1\ ps)^2\ ]$$

For L = 13 mm: $\sigma_{TOF} \sim \sqrt{[4.18^2 + 3.6^2 + 0.63^2 + 4.1^2]} \sim$ **6.9 ps**

Assume $\sigma_{TTS} \sim 32$ ps:



Assume $\sigma_{TTS} \sim 11$ ps:



- **A simple model actually does work quite well, if one assumes $\sigma_{TTS} \sim 32$ ps .**
- **Assume, as Nagoya people suggest: Npe = 40-50 pe / L = 10 mm**
- **Assume a beam size = acceptance of a 5 mm x 5 mm beam counter.**

Low gain operation

Example: SLAC TOF counter

Tests with Photonis MCP-PMT

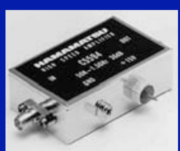
MCP-PMT 85012-501:

- **10 μm MCP hole diameter**
- 64 pixel devices, pad size: 6 mm x 6 mm.

PiLas red laser diode operating in the single photoelectron mode (635 nm):

$$\sigma_{TTS} < \sqrt{(32^2 - 13^2 - 11^2)} = 27 \text{ ps}$$

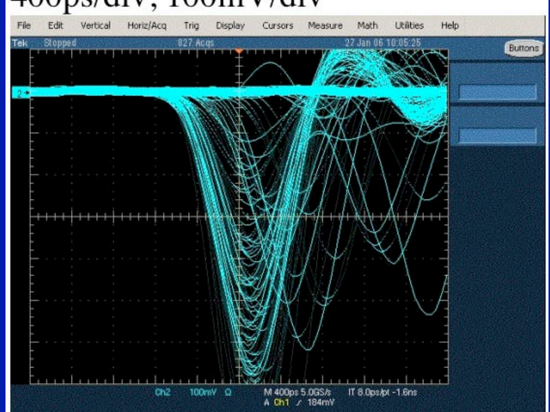
PiLas laser diode   Electronics (TDC mainly)



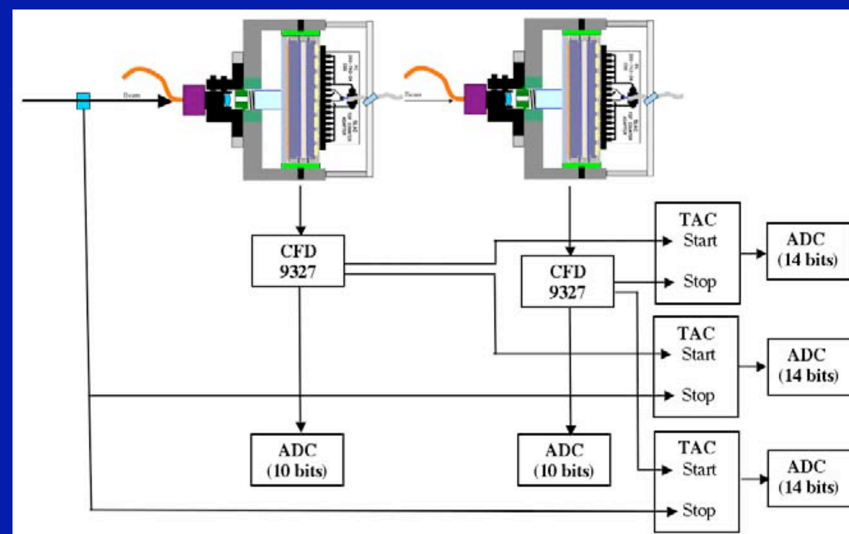
Hamamatsu C5594-44 amplifier

1.5 GHz BW, 63x gain

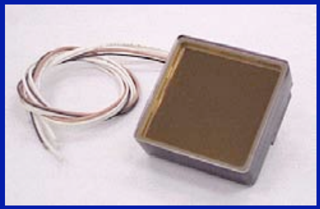
400ps/div, 100mV/div

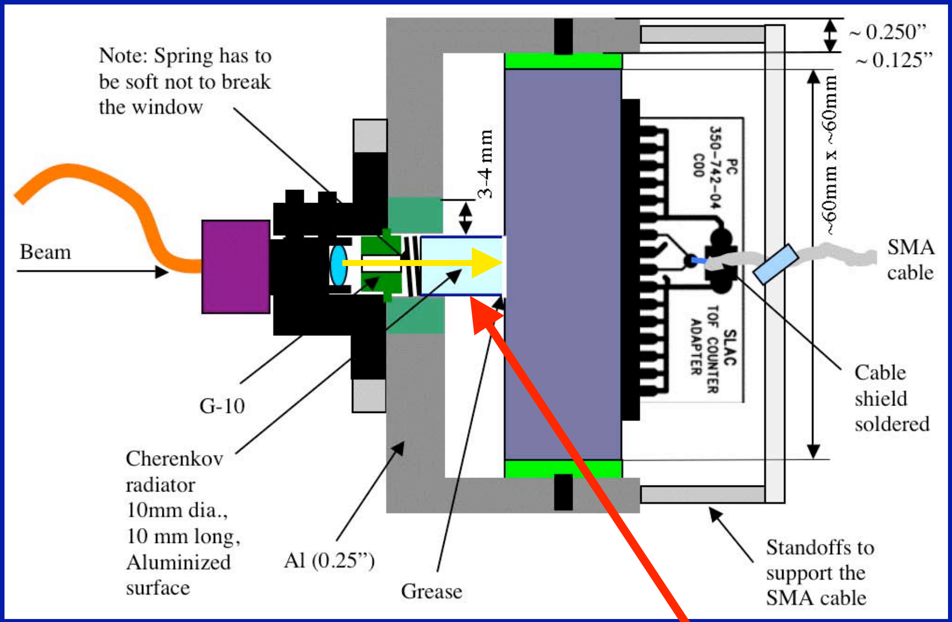


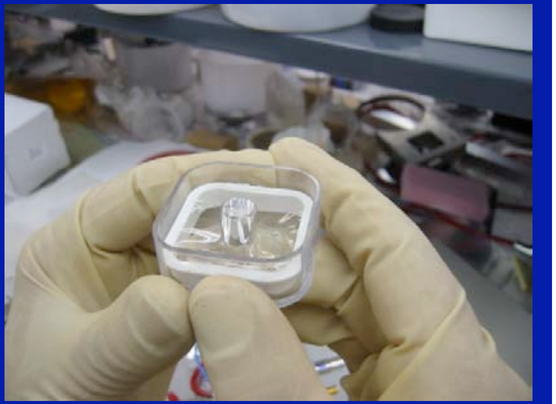
Two identical counters in the beam:



SLAC TOF counter prototype



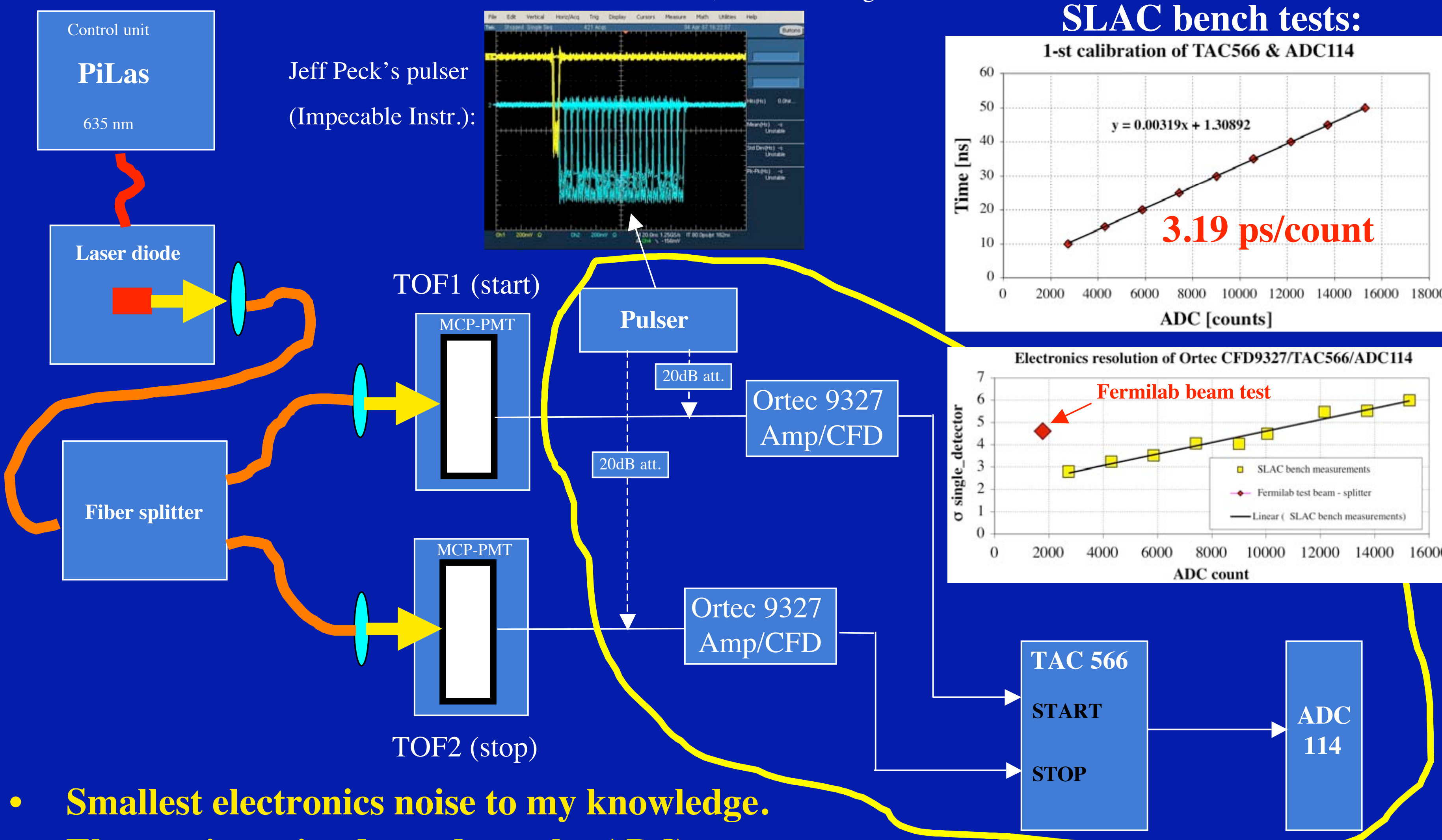




Cylindrical radiator coated with Al on its sides

- **Concentrate light on 4 pads to increase S/N to be able to run low gain**
- **Short together 4 pads to get a signal; all the rest of pads grounded.**
- **A 10mm-long, 10mm dia, quartz radiator, Al-coating on cylinder sides.**

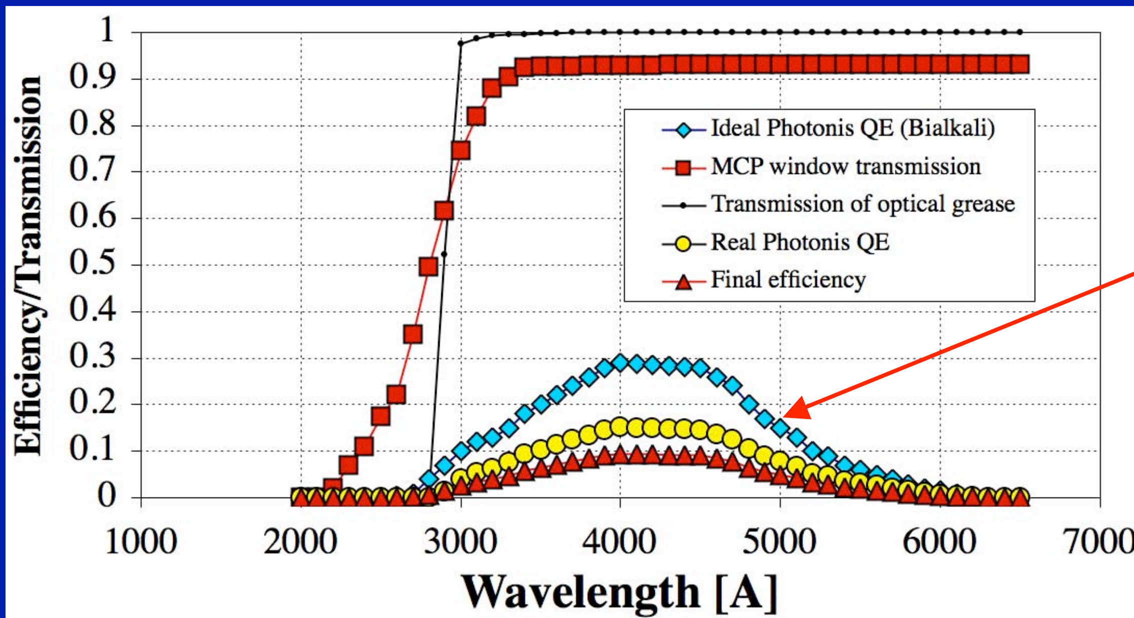
Electronics resolution in the Ortec CFD/TAC/ADC system



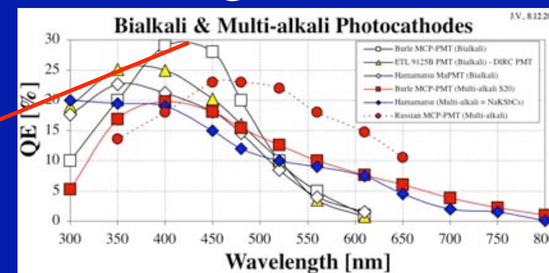
- **Smallest electronics noise to my knowledge.**
- **Electronics noise depends on the ADC count.**
- **Fermilab test beam electronics noise slightly worse than in SLAC bench tests.**

Expected Npe

Wavelength bandwidth of this TOF counter:



QE



Scale down the “optimistic” Burle QE using a luminous sensitivity in blue provided by Photonis for this particular tube

- **Calculation using all known efficiencies: Npe ~ (30 + 42)/2 ~ 36.**
- **Scope test in the Fermilab beam test: Npe ~ 45 ± 10.**

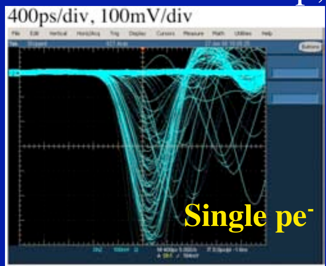
[Procedure to determine Npe: (a) scope measurement of average PH, (b) scope measurent of a cable delay, (c) measure amplifier amplitude attenuation for the same csable delay, (d) gain correction due to a different voltage used in my best resolution measurement]

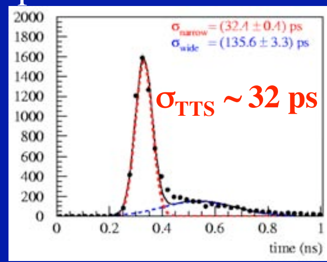
Planacon σ_{TTS} at very high gain

J.Va'vra et al., Nucl.Instr.&Meth. A 572 (2007) 459–462, and my log books 3 & 6, 2006 & 2008

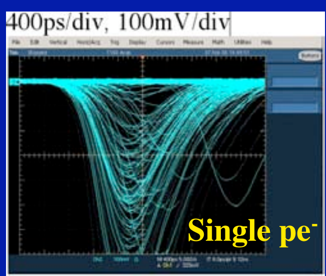
1) ~ 300 MHz BW electronics:

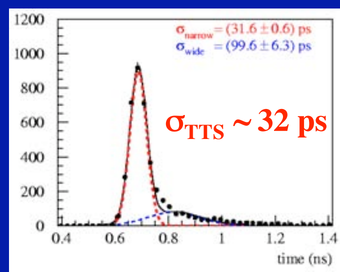
HPK C5594-44 amp, Phillips 715 CFD:





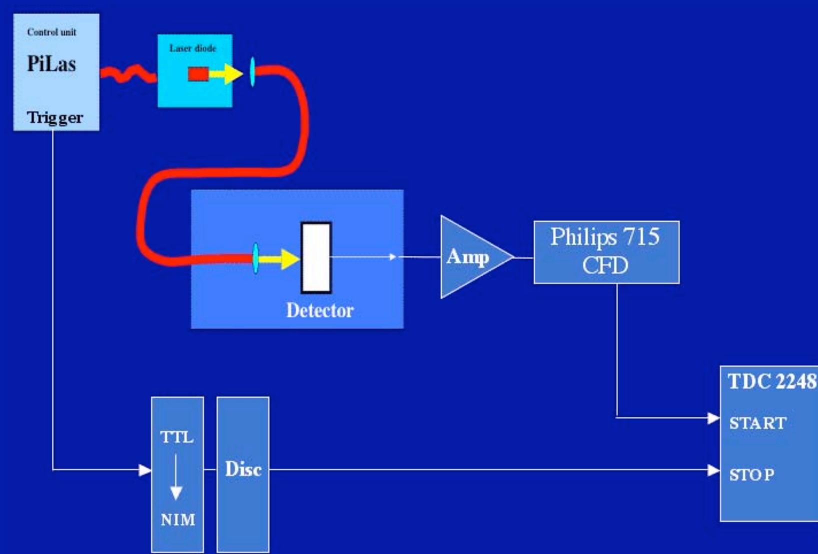
Ortec VT-120 amp.+6dB, Phillips 715 CFD :





- **Slow down amplifiers by a long cable between Amp & CFD** (optimum was found to be ~20ns).

- **Photonis Planacon**, S/N 11180401
- **10 μm MCP hole diameter**
- **2.8 kV**
- **Single pe sensitivity**

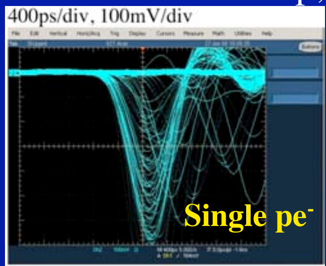


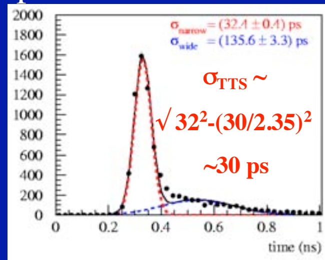
Planacon σ_{TTS} at very high gain

J.Va'vra et al., Nucl.Instr.&Meth. A 572 (2007) 459–462, and my log books 3 & 6, 2006 & 2008

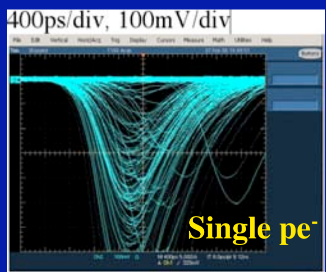
1) ~ 300 MHz BW electronics:

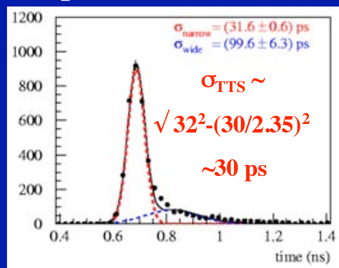
HPK C5594-44 amp, Phillips 715 CFD:





Ortec VT-120 amp.+6dB, Phillips 715 CFD :



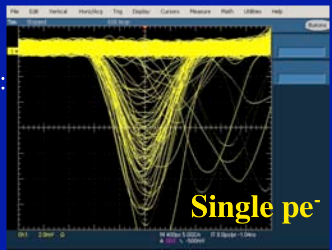


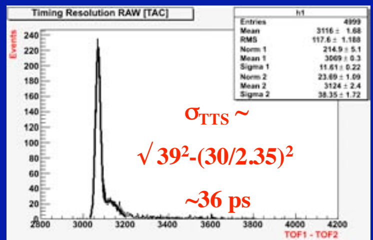
- **Slow down amplifiers by a long cable between Amp & CFD** (optimum was found to be ~20ns).

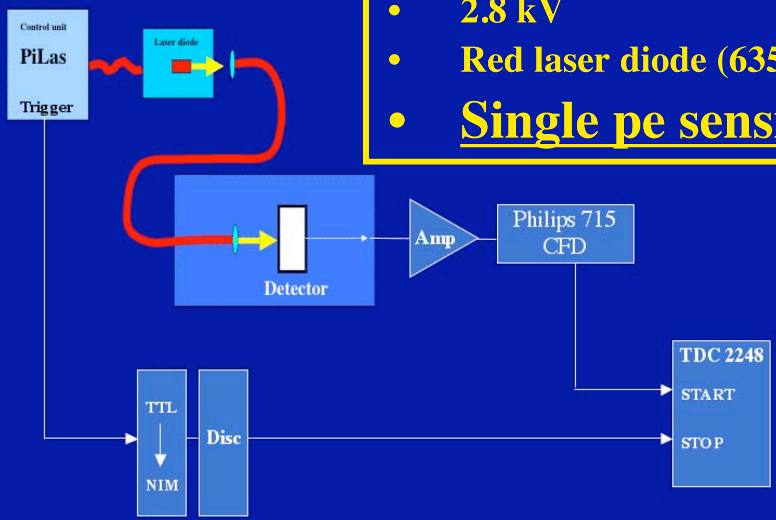
2) ~ 1 GHz BW electronics:

Ortec 9327CFD, TAC566, ADC114:

CFD monitor:





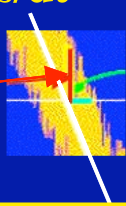


- **Photonis Planacon**, S/N 11180401
- **10 μm MCP hole diameter**
- **2.8 kV**
- **Red laser diode (635 nm)**
- **Single pe sensitivity**

- **CFD timing:**

$$\sigma_{time} = \sigma_{noise} / (ds/dt)_{zero\ crossing\ point}$$

ds/dt



σ_{noise} σ_{time}

Note:

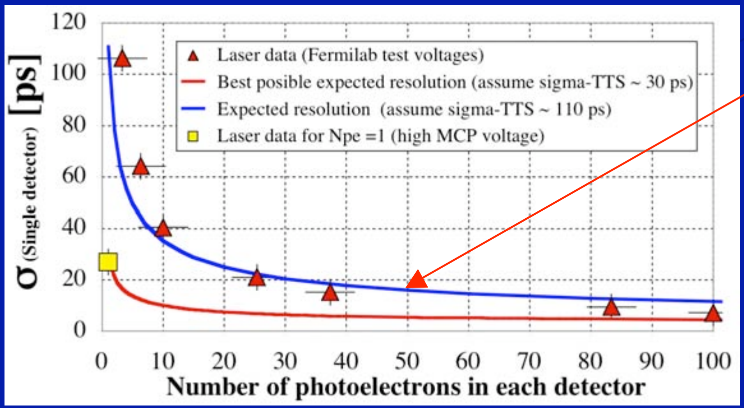
The best results obtained with slower electronics

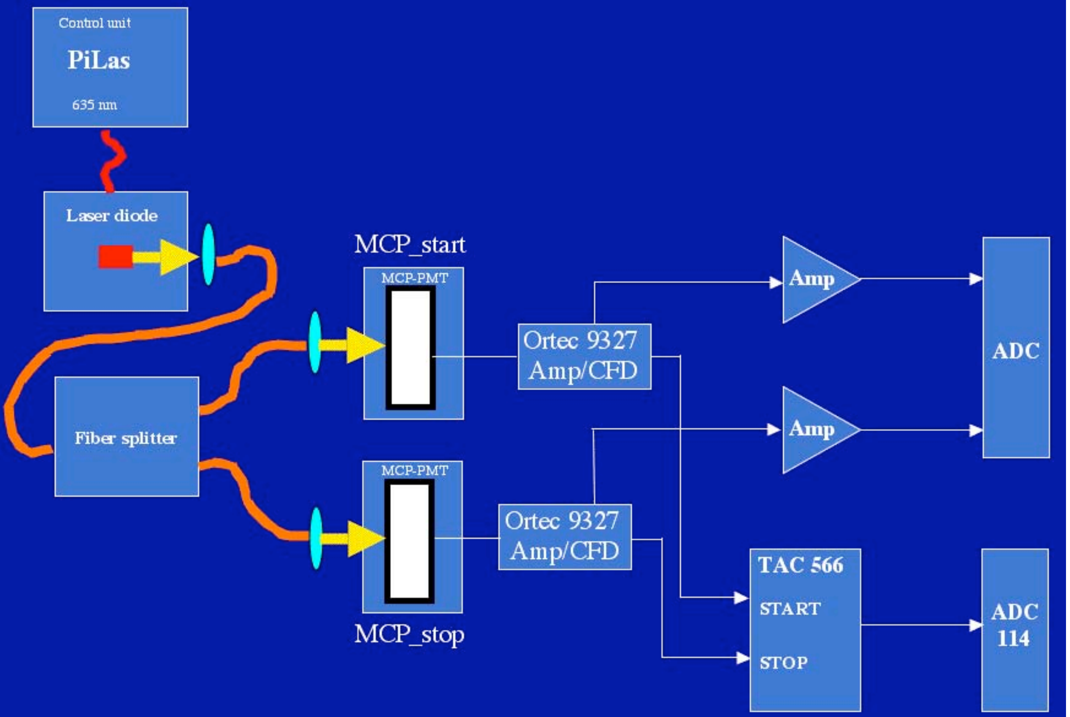
σ_{TTS} at low gain - the same condition as during the beam test

J.Va'vra et al., Nucl.Instr.&Meth. A 595 (2008) 270-273

$$\sigma \sim \sqrt{[\sigma^2_{MCP\text{-}PMT} + \sigma^2_{Laser} + \sigma^2_{Electronics} + \dots]} = \sqrt{[\sigma_{TTS}/\sqrt{N_{pe}})^2} + \sqrt{((FWHM/2.35)/\sqrt{N_{pe}})^2 + (3.1\ ps)^2]}$$

Nominal MCP voltages, G ~2x10^4:



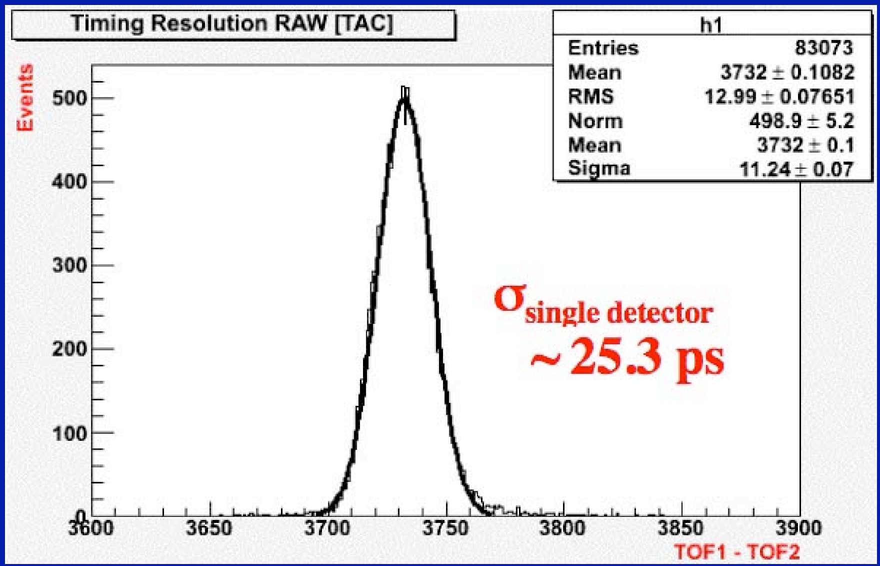


- **Photonis Planacon**, S/N 11180401 & 7300714
- **10 µm MCP hole diameter**
- **2.2 kV & 2.0 kV on MCP-PMTs**
- **Red laser diode (635 nm)**
- **Not sensitive to single pe**
- **Linear for Npe ~ 30-50**

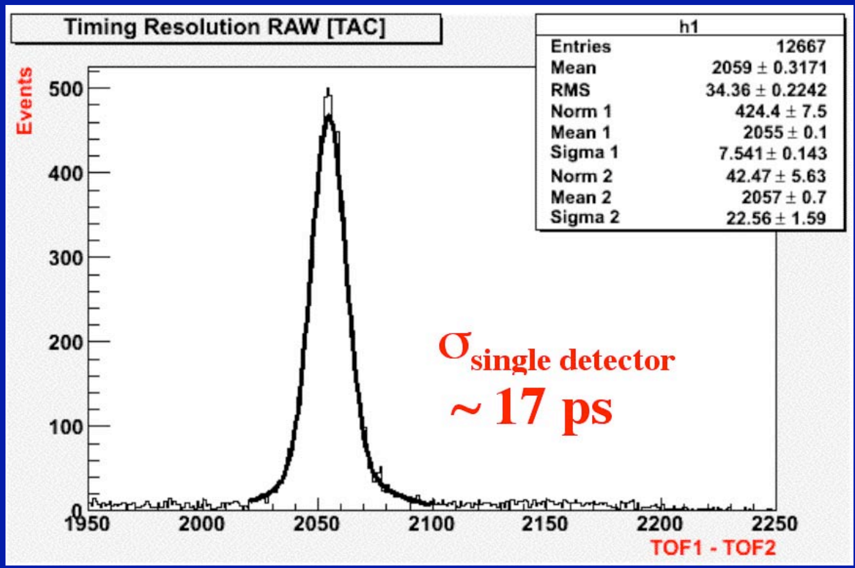
- **The same electronics as in the test beam - Ortec electronics (9327CFD, TAC566, ADC114)**
- **Extrapolating to Npe = 1, one obtains much worse σ_{TTS} ~ 120 ps.**

Beam tests at SLAC and Fermilab

SLAC beam test, 10 GeV e^+:



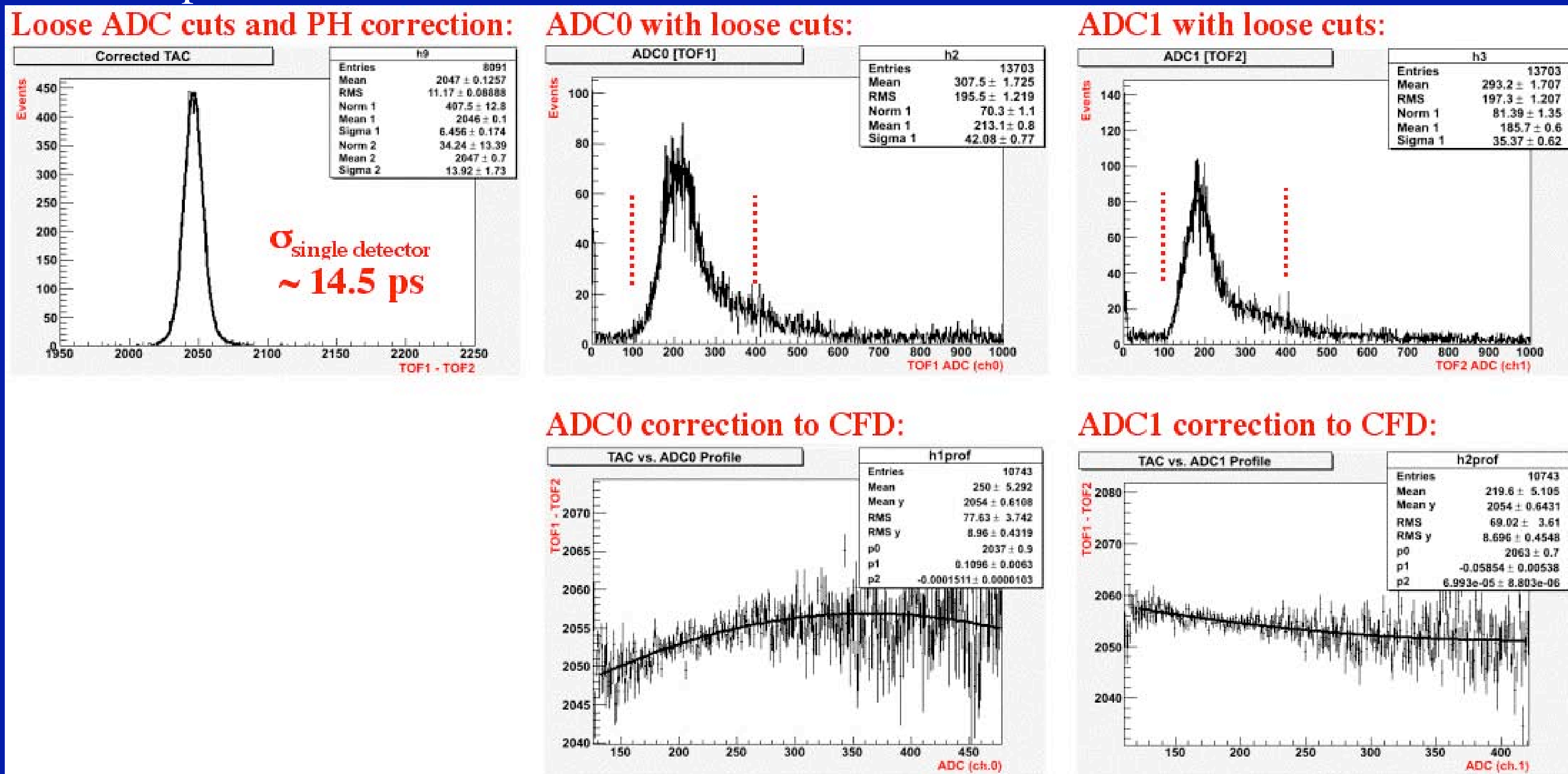
Fermilab beam test, 120 GeV p:



- **All events - no ADC cuts or ADC corrections to timing in these two plots.**
- **<u>Difference between two tests</u>: use a new quartz radiator with a new aluminum coating in the in Fermilab test (coated by Photonis).**

Beam test at Fermilab

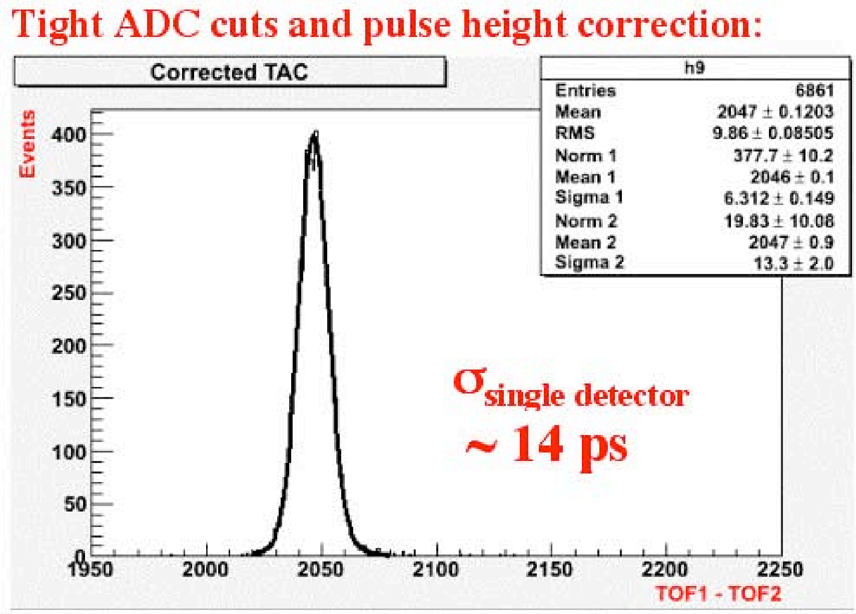
120 GeV protons:

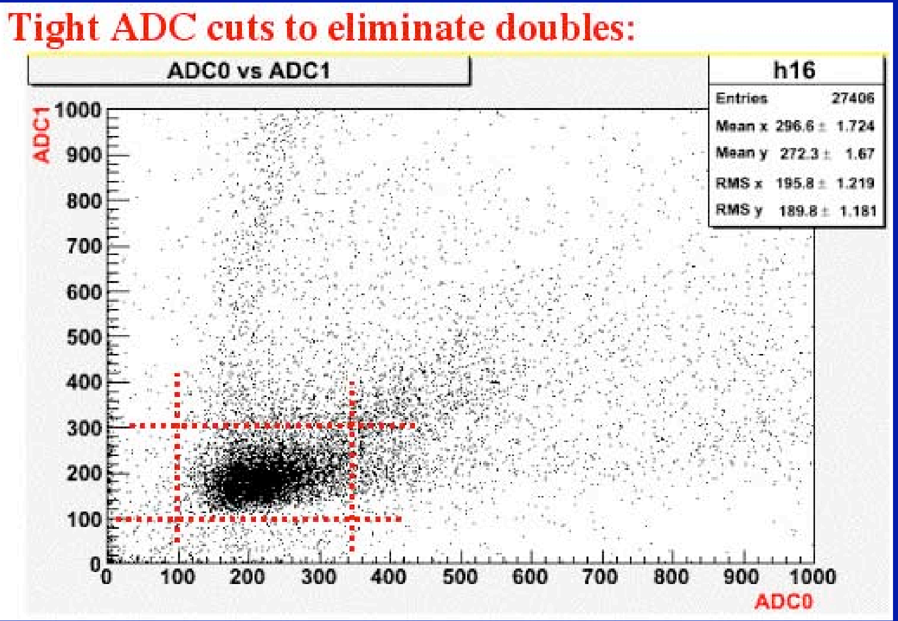


- **ADC correction to CFD timing & <u>loose</u> ADC cuts**

Beam test at Fermilab

120 GeV p:





- **ADC correction to CFD timing & <u>tighter</u> ADC cuts**

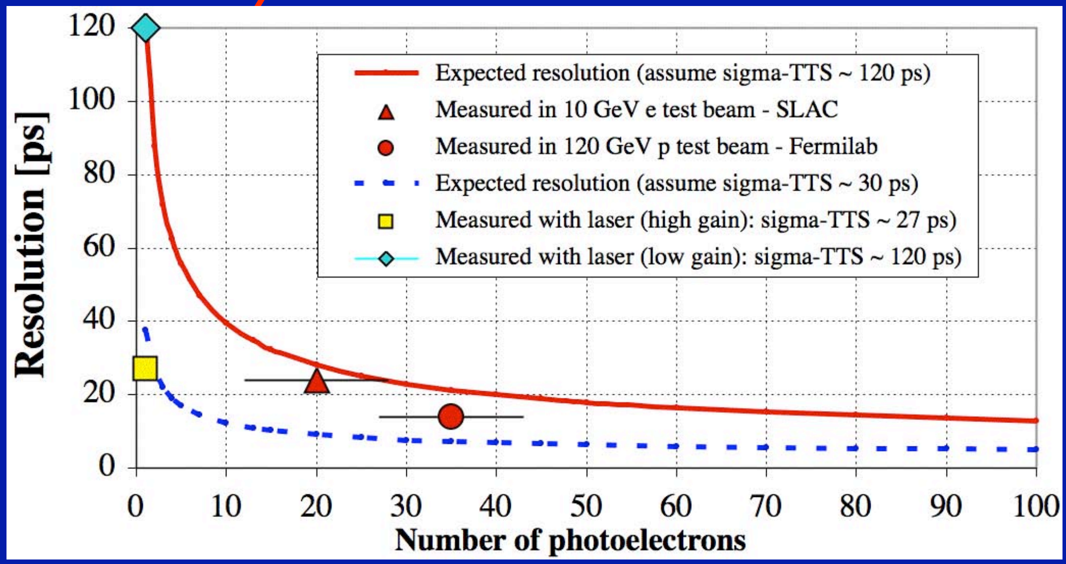
Are the results consistent with expectations ?

$\sigma_{TOF} \sim \sqrt{[\sigma^2_{MCP\text{-}PMT} + \sigma^2_{Radiator} + \sigma^2_{Pad\ broadening} + \sigma^2_{Electronics} + \ldots]} =$

$= \sqrt{[(\sigma_{TTS}/\sqrt{N_{pe}})^2 + (((12*1000\mu m/\cos\Theta_C)/(300\mu m/ps)/n_{group})/\sqrt{(12Npe)})^2 +}$

$+ ((6*1000\mu m/300\mu m/ps)/\sqrt{(12Npe)})^2 + (4.7\ ps)^2\ ]$ **~ 21.5 ps**

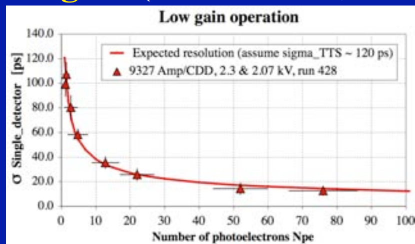
For Npe = 36, contributions from each term: 20.3 ps 4.3 ps 3.4 ps 4.7 ps



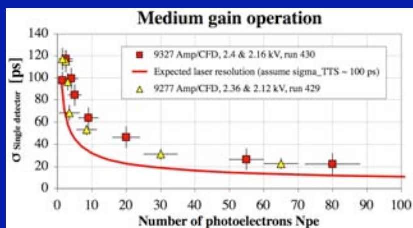
- **Use a calculation for the Fermilab test: Npe ~ (30 + 42)/2 ~ 36.**
- **In principle, one could choose to go via a very high gain route and follow the dashed blue curve to get into a 10 ps regime. For some applications it is possible to consider. To do that one has to consider amp. saturation effects.**

σ_{TTS} = f(gain) with laser & test beam electronics

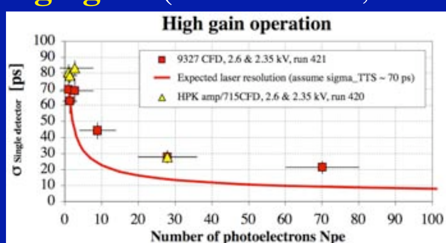
Low gain (2.3&2.07kV, G ~2-3x10^4):



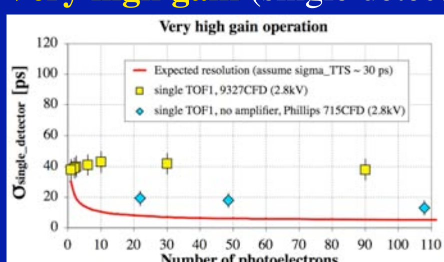
Medium gain (2.36&2.12kV, G ~7x10^4):



High gain (2.6&2.15kV, G ~3x10^5):

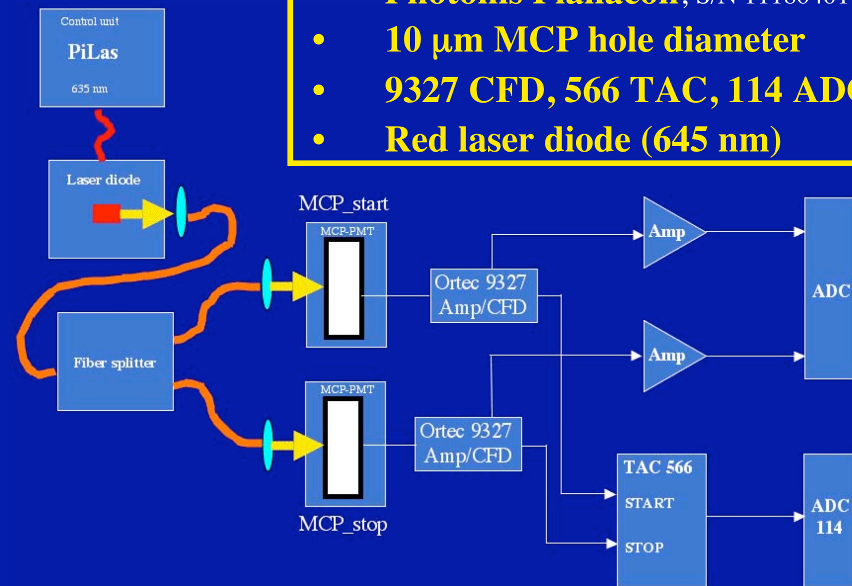


Very high gain (single detector, 2.8 kV, G ~10^6):

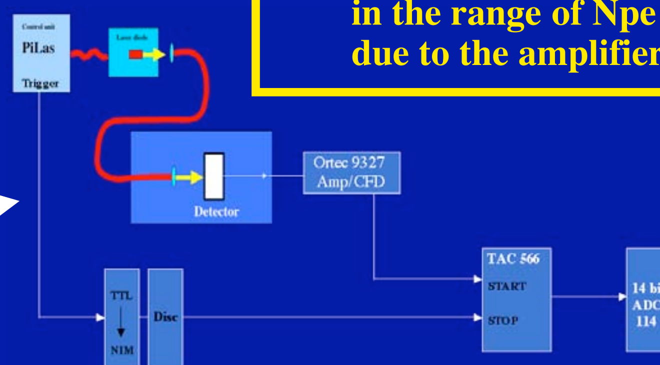


J.Va'vra, log book 6, 2008

- **Photonis Planacon**, S/N 11180401 & 7300714
- **10 µm MCP hole diameter**
- **9327 CFD, 566 TAC, 114 ADC**
- **Red laser diode (645 nm)**



- **Higher gain helps the σ_{TTS} measurement with 9327 CFD, however, it does not help in the range of Npe ~30-50, presumably due to the amplifier saturation.**



Conclusions

- I have outlined two clear choices how to proceed with MCP-based TOF counters:

a) One choice to to run a very high gain with single pe sensitivity, which could lead to a sub-ten ps TOF resolution. However, one may have serious lifetime issues requiring various QE protection solutions in a high bckg condition.

b) Another choice is a low gain operation, where the detector is sensitive to tracks only, which would lead to somewhat worse TOF resolution of ~15ps. On the other hand, one may have, possibly, longer QE lifetimes.